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Reducing Irrigation Water Consumption Added for Onion by Using the Technique of Isolating Sandy Soil with Plastic Sheet Under Matrouh Conditions

Ali A. Abd El-Aziz[1] and Zakaria F. Fawzy [2]

[1]Soil Chemistry and Physics Department., Desert Research Center, Cairo, Egypt.
[2]Vegetable Research Dept., Agriculture and Biological Research Institute, National Research Centre, El-Buhouth St., Dokki 12622, Giza, Egypt.

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ABSTRACT

Onions are among Egypt's most significant vegetable crops, valued for local consumption and agricultural exports. Onions are highly valued for their distinctive pungent flavor and serve as a key ingredient in the cuisine of many regions worldwide. The scarcity of irrigation water is one of the main challenges limiting agricultural production in Egypt's arid and semi-arid regions. An experiment was conducted over two consecutive winter seasons (2021/2022 and 2022/2023) on a private farm in the El Dabaa area, Matrouh Governorate, Egypt. The study aimed to evaluate the impact of different sandy soil covering techniques using plastic sheets: uncovered (UCS), half covered (HCS), and fully covered (FCS), along with varying irrigation water levels (IR = 100, 85, 70, 55, and 40 % based on crop evapotranspiration). The experiment was carried out under both leaky pipe irrigation (LBI) and surface drip irrigation (SDI) systems to assess crop quality parameters, marketable yield (MY), seasonal actual evapotranspiration (ETa), water use efficiency (WUE), irrigation water use efficiency (IWUE), and the yield response factor (Ky) for the winter onion crop (*Allium cepa* L.). The results indicated that the winter onion crop's highest quality parameters and marketable yield were achieved under the FCS, IR = 100%, and LBI treatment in both seasons. In contrast, the lowest seasonal ETa values were recorded at 114.56 mm and 110.67 mm for the two seasons under FCS, IR = 40%, and LBI treatment. Additionally, the highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for the winter onion crop were 20.37 and 14.68 kg/m³ in the first season, and 21.21 and 15.08 kg/m³ in the second season, observed under FCS, IR = 55%, and LBI treatment. Finally, the lowest yield response factor (Ky) values were 0.09 and 0.11 for the two seasons under FCS, IR = 85 %, and LBI treatment. This study demonstrated that cultivating winter onions under FCS, IR = 55%, and LBI treatment could potentially conserve approximately 45% of the applied irrigation water while increasing the marketable yield of the crop by an average of 12% across both seasons compared to the control treatment (UCS, IR = 100%, and SDI treatment).

Keywords: Sandy soil covered, added water levels, Leaky pipe irrigation system, Onion, Actual evapotranspiration, Water use efficiency, Irrigation water use efficiency, Yield response factor.

1. Introduction

Onion (*Allium cepa* L.) is one of the most significant horticultural crops globally. Numerous studies have explored its water requirements and the impact of deficit irrigation on productivity. Economically, onion plays a crucial role, contributing to the commercialization of the rural economy and generating numerous off-farm employment opportunities. (Patel and Rajput 2013). Onion has a shallow root system and is highly sensitive to water stress. Consequently, it is irrigated with light and frequently used to prevent moisture deficiency (Doornebos and Kassam 1979). Water has long been the primary constraint on crop production in arid and semi-arid regions where rainfall is insufficient to meet crop needs. With growing competition for limited water resources and the increasing demand for

Corresponding Author: Ali A. Abd El-Aziz, Soil Chemistry and Physics Department., Desert Research Center, Cairo, Egypt.

agricultural commodities, enhancing water use efficiency and productivity in crop production has become crucial. This is essential to ensure future food security and mitigate the uncertainties posed by climate change (FAO 2012). Excessive irrigation and deep percolation in the region's sandy loam soil reduced water use efficiency and shortages during the crop's critical growth stages (Brown and Butcher 1999). Proper irrigation scheduling is crucial for enhancing various vegetable crops' irrigation water use efficiency (Zotarelli *et al.,* 2009). Achieves plastic sheets for irrigation in arid and semi-arid regions worldwide provide significant benefits by conserving water and managing salt distribution. This is achieved by reducing deep percolation losses (Memon *et al.,* 2017). The marketable yield, WUE, and IWUE of corn increased with the use of mulch treatment compared to no mulch. The results indicated that inhumed spongy clay achieved the highest yield, WUE, and IWUE compared to surface and subsurface drip irrigation systems. Therefore, it is a crucial method for enhancing water use efficiency in corn cultivation under arid and semi-arid conditions (Kanani *et al.,* 2016). Applying mulch is acknowledged as a successful strategy for lowering soil evaporation and conserving water (Zhang *et al.,* 2014). Mulching the soil also increases water use efficiency (WUE). Any material applied to the soil's surface to shield it from sunlight and lower evaporation is called mulch. Mulch comes in various forms, including wood, plastic film, grass, rice straw, and wheat straw (Yaghi *et al.,* 2013). The moisture content decreased by roughly 52% at a depth of 2 cm, 83% at 5 cm, and 95% at 10 cm in mulched soil. The moisture content of the mulched soil's top layer (0–60 cm) was generally higher than that of bare soil (Kumar and Lal 2012). Mulching successfully inhibits weed development, lowers surface soil evaporation, and stops salt buildup in the soil profile (Terasaki *et al.,* 2009). Numerous experiments have been conducted to examine the impact of drip irrigation and plastic mulch on crop production improvement across a range of agro climatic zones and soil conditions. According to specific research, yields raised roughly 20–60% when drip irrigation was used (Sivanappan *et al.,* 1974). The thick, non-permeable polyethylene sheets were buried 30 to 40 cm below the soil surface, 60 cm wide and 0.06 mm thick, beneath the irrigation lines. The findings indicated that the soil's moisture content and storage capacity had increased in the root-spreading area, whereas the rate of soil deep penetration had decreased (Barth 1995). The combination of fully covered sandy soil (FCS), 100% applied irrigation water (IR), and subsurface drip irrigation (SSDI) produced the maximum commercial production and quality metrics of summer squash fruits. In contrast, the FCS, IR = 40%, and SSDI treatments showed the lowest seasonal actual evapotranspiration (ETa) values. Furthermore, when compared to the control treatment (uncovered soil (UCS), IR = 100%, and surface drip irrigation (SDI), water use efficiency (WUE) and irrigation water use efficiency (IWUE) increased significantly under FCS, IR = 60%, and SSDI treatment by roughly 176% and 94% in the first season and 162% and 91% in the second season, respectively. Additionally, with FCS, IR = 90%, and SSDI treatment, the lowest crop yield response factor (Ky) values for summer squash fruits were 0.03 and 0.05 for the first and second seasons, respectively. In comparison to the control treatment (UCS, IR = 100%, and SDI), summer squash treated with FCS, IR = 60%, and SSDI can save roughly 42–44% of the applied irrigation water while increasing marketable yield by roughly 16% and 15% for the two seasons, respectively (Sadik and Ali 2018). Sandy soil has a problem with deep percolation and significant levels of infiltration when standard irrigation techniques are utilized. On the other hand, small-scale irrigation techniques like drip and leaky pipes may give superior results because they minimize deep percolation by feeding the root system precisely the right amount of water at the proper rate. Along the leaky pipe, cross-sectional measurements of the moisture patterns were performed, and the wetting front's vertical and horizontal expansion was documented. Because it gradually controls deep percolation and requires minimal pressure, the results demonstrate that a leaky pipe system performs effectively in light-textured soils (Golabi and Akhoonali 2008; Rasheed 2021). During winter faba bean cultivation, the leaky pipe irrigation system (LBI) with 100% applied irrigation water (IR) and a potassium humate rate (PHR) of 8 kg fed^{-1} produced the highest values for marketable seed yield and quality criteria, except seed carbohydrate and protein content. In contrast, the LBI, IR = 55%, and PHR = 0 kg fed^{-1} treatments resulted in the lowest seasonal actual evapotranspiration (ETa) values for faba beans. Furthermore, in comparison to the control treatment (sprinkler irrigation system (SI), IR = 100%, and PHR = 0 kg fed^{-1}), the winter faba bean's water use efficiency (WUE) and irrigation water use efficiency (IWUE) under LBI, IR = 70%, and PHR = 8 kg fed^{-1} increased significantly by roughly 178% and 134% in the first season, and 176% and 131% in the second season, respectively. Furthermore, compared to the control treatment (SI, IR = 100%, and PHR = 0 kg fed^{-1}), growing winter faba beans under El-Baharia Oasis conditions with the LBI, IR = 70%, and PHR = 8 kg fed^{-1} treatment can save about 30% of the applied irrigation water while increasing the marketable seed yield by an average of 36% over both seasons (Ali 2023). The current study investigated the effectiveness of a novel leaky pipe and a state-of-the-art drip irrigation system for subterranean lettuce watering. According to the results, the porous pipe technology increased total fresh biomass by 9%, using 35% less water than drip irrigation. Consequently, the water consumption efficiency was much more significant at 58 kg/m^3 compared to 34.4 kg/m^3 with drip irrigation (Kunze *et al.,* 2021). Under water-poor conditions, the drip irrigation system is one of the most efficient ways to boost water use efficiency. Modern technology must be studied, researched, and used to rationalize water consumption in agricultural production (Atta *et al.,* 2011). Several irrigation techniques have been used to produce the onions. The most popular technique for growing onions is drip irrigation (4 l/h), which has benefits in terms of efficiency and uniformity. In order to adequately meet crop water requirements, farmers using this type of irrigation faced the primary challenge of maintaining system efficiency through proper timing and water application. Therefore, this article presents the effects of various deficit irrigation treatments (60, 80, and 100% ETc) on water productivity and onion yield under mulching and drip irrigation. To achieve the best bulb onion yield in areas where water was not in short supply, it was recommended to use a drip irrigation system and provide 100% crop evapotranspiration with straw mulch irrigation water application level throughout the growing season (Dache and Zewudie 2024). Water resources are limited, so deficit irrigation (DI) gives higher economic returns than maximizing yields per water unit. Due to high water productivity, deficit irrigation may expand the irrigated area (Nurga *et al.,* 2022). Deficit irrigation is one of the most important methods for preserving water in agricultural production. It is a technique to increase water use efficiency (WUE), decrease water demand, and increase crop yields, including maize, tomatoes, onions, and fava beans. Applying less water than what the crop needs to flourish is the unambiguous definition of it (Mohamed Abd El-Aziz 2020; Basma and Reham 2022; Tesfaye 2023). Deficit irrigation enhances the water use efficiency of onions. The highest water productivity can be achieved by applying a 70% ETc water deficit irrigation strategy. Considering the yield response factor (Ky), an 80% ETc application is marginal, and exceeding this threshold leads to significant yield losses. Implementing deficit irrigation (DI) by up to 20% can save 45 to 108 mm of irrigation water compared to full irrigation. DI optimizes water productivity and irrigation management by conserving water while maintaining soil moisture levels below the optimum throughout the growing season (Enchalew *et al.,* 2016). Compared to the other treatments, the ideal irrigation water application level was suggested to be 70% ETc based on water productivity, economic visibility, total yield, yield reduction percentage, and yield response factor. Onion production in water-scarce areas should not employ a complete irrigation water application since the water productivity value achieved by 100% ETc application level was very low. Farmers and other users should implement the deficit irrigation approach in water-restricted areas to save limited water resources (Lalisa *et al.,* 2022). It is generally known that the yield response factor causes crop output to decrease whenever water stress enters the root zone during a deficient irrigation water supply, and it also decreases when irrigation is excessive. Irrigation experiments that use various irrigation techniques can demonstrate the connection between crop output and water stress (Amer 2010). The yield response factor serves as an indicator of a crop's sensitivity to deficit irrigation. A yield response factor greater than one indicates that the predicted yield reduction increases as the level of deficit irrigation rises. Therefore, this factor is commonly used in irrigation management to optimize water use efficiency (Steduto *et al.,* 2012). This study aimed to examine the impact of using plastic sheets of sandy soil covering techniques on cultivation lines, combined with varying irrigation water levels, under-surface drip, and leaky pipe irrigation systems. The research focused on winter onion crop production, quality parameters, actual evapotranspiration, water use efficiency, irrigation water use efficiency, and yield response factor.

2. Materials and Methods

2.1. Experiments layout

Field experiments were conducted in the El Dabaa area, Matrouh Governorate, Egypt, at a private farm (31° 05′ 19″ N, 28° 25′ 42″ E, 18 m a.s.l) during two consecutive winter seasons (2021/2022 and 2022/2023). The study followed a split-split plot design with three replicates, where each experimental plot measured 50 m² and was separated by a 2 m wide barren strip to prevent horizontal water infiltration. Statistical analysis was performed using the Co-state software program, following the

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methods of (Snedecor and Cochran 1989). Winter onion (*Allium cepa L.*) was irrigated using five different irrigation water levels (IR = 100%, 85%, 70%, 55%, and 40% of crop evapotranspiration) under three sandy soil cover techniques CST for cultivation lines using plastic sheets, uncovered (UCS), half covered (HCS), and fully covered (FCS). These treatments were tested using two irrigation methods: leaky pipe irrigation (LBI) and surface drip irrigation (SDI). To apply the half-covered soil technique, canals were excavated along the cultivation lines using a ditcher machine, with a spacing of 1 meter between each canal and the other and a depth of 45 cm. These canals were lined with 200 µm thick plastic sheets before being refilled with soil. However, the top 10 cm of the soil surface was left uncovered to facilitate soil servicing operations without damaging the buried plastic sheets. In the fully covered soil technique, the subsurface soil was treated similarly, with plastic sheets covering the canals and the soil surface covered with perforated plastic sheets, allowing only the plants to emerge. For the winter onion crop, the following parameters were measured: plant height (PH) cm, number of leaf plants (NLP), bulb weight (BW) g, bulb diameter (BD) cm, bulb total soluble solid (TSS) %, bulb protein content (BPC) %, and marketable yield (MY) Mg/h. Also, the actual evapotranspiration (ETa) mm, water use efficiency (WUE) kg m^{-3}, irrigation water use efficiency (IWUE) kg m^{-3}, and yield response factor (Ky) were computed for all cover soil techniques at various applied irrigation water levels under leaky pipe and surface drip irrigation for all winter onion plant treatments.

2.2. Soil characteristics

Soil samples intended for planting were collected to analyze their physical and chemical properties. The methodological procedures adhered to the guidelines outlined by Page *et al.* (1982) and Klute (1986), respectively (Tables 1&2).

Table 1: Some physical characteristics of experimental soil.

Soil depth cm	Particle size distribution %					Textural class	OM %	ρ_b g/cm^3	Ks cm/h	FC %	WP %	AW %
	C. sand	M. sand	F. sand	Silt	Clay							
0-20	6.38	18.24	62.46	7.19	5.73	S	0.43	1.58	12.26	15.75	5.36	10.39
20-40	5.85	17.48	61.72	8.04	6.91	S	0.39	1.56	12.13	16.89	5.54	11.35
40-60	5.63	17.16	60.89	8.73	7.59	S	0.35	1.53	11.89	17.61	5.97	11.64

Table 2: Some chemical characteristics of experimental soil

Soil depth cm	EC dS m^{-1}	pH	$CaCO_3$ %	CEC cmole kg^{-1}	Soluble ions (meq/l) in the saturated soil paste extract							
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}
0-20	2.39	7.87	19.41	8.79	11.74	1.39	6.86	3.91	9.79	2.84	-	11.27
20-40	2.47	7.59	18.84	8.92	11.81	1.46	7.14	4.29	10.24	2.97	-	11.49
40-60	2.61	7.32	17.57	9.04	12.39	1.53	7.51	4.67	10.87	3.19	-	12.04

2.3. Quality of irrigation water

The chemical analysis of the irrigation water used was performed according to the methods described by Ayers and Westcot (1994), as presented in (Table 3).

Table 3: Some chemical analysis for irrigation water

Sample	pH	EC dS m^{-1}	SAR	Soluble cations, meq/l				Soluble anions, meq/l			
				Na^+	K^+	Ca^{++}	Mg^{++}	CL^-	HCO_3^-	$CO_3^=$	$SO_4^=$
Mean	7.68	1.85	3.58	7.21	3.17	4.63	3.49	4.47	6.95	-	7.08

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2.4. Reference evapotranspiration (ETo)

The reference evapotranspiration (ETo) cleared in Table (4) was calculated using the Cropwate (8) software based on Penman-Monteith equation FAO 56 method (Allen *et al.,* 1998).

Table 4: Calculated reference evapotranspiration (mm day^{-1}) through winter onion growth period

Seasons	Month	October	November	December	January	February	March
2021/2022	ETo mm day^{-1}	4.53	3.69	3.12	2.96	3.54	3.97
2022/2023		4.59	3.76	3.17	3.03	3.61	4.05

2.5. Crop evapotranspiration (ETc)

The crop evapotranspiration (ETc) presented in Table (5) was calculated using the following equation:

$ETc = Kc_{FAO} \cdot ETo$ **(mm day^{-1})** Allen *et al.* (1998)

Where: Kc_{FAO} : Crop coefficient from FAO No.(56).

ETo : Reference crop evapotranspiration, mm day^{-1}.

Table 5: Calculated crop evapotranspiration (mm day^{-1}) through winter onion growth period

Stages	Initial	Develop.	Mid	Late	Seasonal
Planting date	13/10 to 27/10	28/10 to 21/11	22/11 to 30/1	31/1 to 11/3	13/10 to 11/3
Period length (day)	15	25	70	40	150
Kc_{FAO} (-)	0.50	0.78	1.05	0.60	--------
Season 2021/2022					
ETo (mm)	67.95	95.61	218.73	145.75	528.04
$ETc_{100\%}$ (mm)	33.98	74.58	229.67	87.45	425.68
Eff. Rainfall (mm)	7	16	69	23	115
Season 2022/2023					
ETo (mm)	68.85	97.32	223.01	148.66	537.84
$ETc_{100\%}$ (mm)	34.43	75.91	234.16	89.20	433.70
Eff. Rainfall (mm)	9	21	75	27	132

2.6. Applied irrigation water levels IR:

The amounts of applied irrigation water levels (IR) for winter onion crop indicated in Table (6) were estimated by using the equation:

$IR_{100, 85, 70, 55, 40\%} = (ETc - pe)Kr / Ea) + LR$ **(mm period^{-1})** Keller and Karmeli (1974)

Where: Kr: Correction factor for limited wetting according to the 80% onion canopy coverage, Kr = 0.90. (Smith 1992).

Ea: Irrigation efficiency for drip and leaky pipe irrigation systems 90% (Allen *et al.,* 1998).

Pe: Effective rainfall, 115 mm season^{-1}.

LR: Leaching requirements, under salinity levels of irrigation water (0.17 x ETc), mm.

Table 6: Calculated added irrigation water levels (IR), mm through winter onion plant growth period.

IR %	Applied Irrigation water (mm)				
	Growth Stages				
	Initial	Development	Mid	Late	Seasonal
	Season 2021/2022				
100	32.90	71.59	200.75	79.71	384.95
85	27.97	60.85	170.64	67.75	327.21
70	23.03	50.11	140.53	55.80	269.47
55	18.10	39.37	110.41	43.84	211.72
40	13.16	28.64	80.30	31.88	153.98
	Season 2022/2023				
100	31.43	68.16	200.03	77.76	377.38
85	26.72	57.94	170.03	66.10	320.79
70	22.00	47.71	140.02	54.43	264.16
55	17.29	37.49	110.02	42.77	207.57
40	12.57	27.26	80.01	31.10	150.94

2.8. Actual evapotranspiration

ETa = (M2 % – M1 %) /100. db . D **(mm)** Doorenbos and Pruitt (1984)

Where:
M_2 **:** Moisture content after irrigation %.
M_1 **:** Moisture content before irrigation %.
d_b **:** Specific density of soil .
D **:** Mean depth, mm.

2.9. Water use efficiency

WUE = MY / Eta **(kg m^{-3})** Howell *et al.* (2001)

Where:
MY: Marketable yield of onion crop, (t h^{-1}).

2.9. Irrigation Water use efficiency

IWUE = MY / IR **(kg m^{-3})** Michael (1978)

Where:
IR : Seasonal applied irrigation water, (m3), Table (6).

2.10. Yield response factor (Ky)

$$\left[1-\frac{MY}{Y_m}\right]=K_y\left[1-\frac{ETa}{ETm}\right]$$ (-) Allen *et al.* (1998)

Where: ETa : Actual evapotranspiration, mm $season^{-1}$.
ETm : Crop evapotranspiration (without stress), mm $season^{-1}$.
Ym : Maximum yield at $IR_{100\,\%}$, t h^{-1}.

3. Results and Discussion

3.1. Effect of CST and IR on quality parameters for onion crop under SDI and LPI irrigation systems

The data in Tables 7 and 8 show that the quality parameters of the winter onion crop, including plant height (PH) cm, number of leaves per plant (NLP), bulb weight (BW) g, bulb diameter (BD) cm, total soluble solids (TSS) %, and bulb protein content (BPC) %, improved with increasing irrigation water application across all treatments. Additionally, the fully covered soil (FCS) technique exhibited significant superiority over the uncovered soil (UCS) and half-covered soil (HCS) techniques. Leaky pipe irrigation (LBI) also had a notable effect compared to surface drip irrigation (SDI). This trend was consistent across both the 2021/2022 and 2022/2023 seasons. The highest values for PH, NLP, BW, BD, TSS, and BPC were observed under the FCS, IR = 100%, and LBI treatment, reaching (86.12 cm, 12.43, 96.84 g, 6.45 cm, 14.35%, and 13.83%) in the first season and (88.37 cm, 12.76, 97.80 g, 6.57 cm, 14.61%, and 14.07%) in the second season. Conversely, the lowest values were recorded under the UCS, IR = 40%, and SDI treatment, with (37.79 cm, 7.23, 33.84 g, 3.41 cm, 9.21%, and 8.43%) in the first season and (38.80 cm, 7.42, 33.97 g, 3.47 cm, 9.38%, and 9.58%) in the second season. These findings align with previous research, (Barth 1995; Sadik and Ali 2018; Rasheed 2021; Ali 2023; Dache and Zewudie 2024).

Table 7: Effect of CST and IR on PH, NLP and BW of onion crop under LBI and SDI irrigation systems for seasons 2021/2022 and 2022/2023.

IS	CST	IR (%)	PH (cm)		NLP (-)		BW (g)	
			1st	2nd	1st	2nd	1st	2nd
SDI	UCS	100	71.68c	73.49c	9.81h	10.07i	71.74e	72.85e
		85	68.46d	70.27d	9.75i	10.01i	69.37e	70.11e
		70	59.03e	60.61f	9.42j	9.68k	53.72g	54.21g
		55	51.52f	52.83g	8.89k	9.13l	44.05i	44.21i
		40	37.79h	38.80i	7.23o	7.42p	33.84j	33.97j
	HCS	100	75.26c	77.32b	10.56e	10.84g	83.21c	84.14c
		85	73.01c	74.98c	10.34f	10.62g	81.07c	81.66c
		70	68.13d	69.85d	10.11g	10.38h	72.66e	72.97e
		55	57.98e	59.53f	9.59j	9.83k	54.67g	55.03g
		40	43.52g	44.71h	7.78n	7.99o	41.94i	42.07i
	FCS	100	78.74b	80.92a	11.24c	11.54d	89.50b	90.55b
		85	77.97b	80.09a	11.07c	11.37e	88.08b	88.80b
		70	74.51c	76.47b	10.82d	11.11f	83.49c	84.11c
		55	68.35d	70.21d	10.51e	10.79g	71.99e	72.46e
		40	46.87f	48.13g	8.49l	8.72m	49.10h	49.39h
LPI	UCS	100	80.31a	82.53a	10.71d	11.01f	77.28d	78.05d
		85	78.92b	81.07a	10.68d	10.97f	74.93e	75.42e
		70	69.36d	71.21d	10.35f	10.63g	58.62f	58.95f
		55	58.54e	60.15f	9.89h	10.16h	47.45h	47.71h
		40	41.78g	42.90h	8.13m	8.35n	36.76j	36.91j
	HCS	100	83.25a	85.43a	11.65b	11.97c	89.24b	90.24b
		85	81.83a	84.05a	11.47b	11.78c	87.25b	88.08b
		70	78.51b	80.67a	11.24c	11.55d	78.64d	79.19d
		55	64.74d	66.51e	10.76d	11.06f	60.29f	60.86f
		40	48.39f	49.69g	8.81k	9.05l	46.55h	46.94h
	FCS	100	86.12a	88.37a	12.43a	12.76a	96.84a	97.80a
		85	83.65a	85.81a	12.29a	12.62a	95.66a	96.30a
		70	81.47a	83.52a	12.05a	12.38b	91.38a	91.84a
		55	76.91b	78.98b	11.82b	12.14b	80.11c	80.71c
		40	51.39f	52.74g	9.67i	9.93j	57.25f	57.59f

IS: irrigation systems, **SDI:** surface drip irrigation, **LPI:** leaky pipe irrigation, **CST:** cover soil techniques, **UCS:** uncovered soil technique, **HCS:** half-covered soil technique, **FCS:** fully covered soil technique, **IR:** added irrigation water levels, **PH:** Plant height, **NLP:** number of leaf plant, **BW:** bulb weight.

Table 8: Effect of CST and IR on BD, TSS and BPC of onion crop under LBI and SDI irrigation systems for seasons 2021/2022 and 2022/2023.

IS	CST	IR (%)	BD (cm)		TSS (%)		BPC (%)	
			1st	2nd	1st	2nd	1st	2nd
SDI	UCS	100	4.87j	4.95j	11.23k	11.44l	10.65i	10.83k
		85	4.81k	4.89j	11.15l	11.36m	10.59j	10.77k
		70	4.56l	4.64k	10.89n	11.09o	10.34k	10.52l
		55	4.23m	4.30l	10.64o	10.83p	9.97m	10.14o
		40	3.41o	3.47n	9.21q	9.38r	8.43o	8.58q
	HCS	100	5.24g	5.33g	11.71h	11.93j	11.15h	11.34i
		85	5.21g	5.30g	11.67h	11.89j	11.11h	11.30i
		70	5.13h	5.22h	11.63i	11.84j	11.04h	11.23i
		55	4.85j	4.93j	11.35j	11.56k	10.72i	10.91j
		40	4.27m	4.34l	9.87p	10.05q	9.00n	9.16p
	FCS	100	5.75d	5.85e	12.63e	12.88g	12.12e	12.33e
		85	5.73d	5.83e	12.59e	12.83g	12.09e	12.30e
		70	5.69d	5.79e	12.55e	12.79g	12.03e	12.24f
		55	5.62e	5.72e	12.47f	12.71g	11.85f	12.06g
		40	4.98i	5.07i	11.04m	11.25n	10.17l	10.34m
LPI	UCS	100	5.49f	5.59f	12.78d	13.02e	12.17e	12.38e
		85	5.43f	5.53f	12.71d	12.95f	12.12e	12.32e
		70	5.17h	5.26h	12.43f	12.66h	11.89f	12.09g
		55	4.81k	4.90j	12.25g	12.48i	11.68g	11.87h
		40	3.95n	4.02m	10.93n	11.13o	10.06m	10.23n
	HCS	100	5.92c	6.03c	13.41b	13.65c	12.79c	13.01c
		85	5.87c	5.98c	13.38b	13.63c	12.76c	12.97c
		70	5.81d	5.92d	13.34b	13.58c	12.70c	12.92c
		55	5.49f	5.58f	12.97c	13.21d	12.43d	12.64d
		40	4.95i	5.04i	11.63i	11.84j	10.67i	10.86j
	FCS	100	6.45a	6.57a	14.35a	14.61a	13.83a	14.07a
		85	6.42a	6.54a	14.32a	14.59a	13.81a	14.04a
		70	6.38a	6.50a	14.29a	14.55a	13.76a	14.00a
		55	6.31b	6.43b	14.23a	14.49b	13.69b	13.92b
		40	5.73d	5.84e	12.97c	13.21d	12.05e	12.26f

IS: irrigation systems, **SDI:** surface drip irrigation, **LPI:** leaky pipe irrigation, **CST:** cover soil techniques, **UCS:** uncovered soil technique, **HCS:** half-covered soil technique, **FCS:** fully covered soil technique, **IR:** added irrigation water levels, **BD:** bulb diameter, **TSS:** bulb total soluble solid, **BPC:** bulb protein content.

3.2. Effect of CST and IR on MY for onion crop under SDI and LPI irrigation systems

Data in Figures 1 and 2 indicate that the marketable yield (MY) of the winter onion crop (Mg h^{-1}) decreases as irrigation water levels (IR) decrease across all treatments. However, the FCS technique demonstrated significant superiority over the UCS and HCS techniques in all treatments. Additionally, LBI had a more pronounced impact than SDI. This trend remained consistent for both the 2021/2022 and 2022/2023 seasons. The highest MY values were recorded under the FCS, IR = 100%, and LBI treatment, reaching 37.57 and 37.94 Mg h^{-1} for the two seasons, respectively. In contrast, the lowest MY values were observed under the UCS, IR = 40%, and SDI treatment, with 13.13 and 13.18 Mg h^{-1} for the respective seasons; These outcomes could be explained by the complete covering of the sandy soil with a plastic sheet increases the soil's storage capacity by preventing deep percolation and surface soil evaporation compared to Uncovered and half-covered sandy soil approaches; this maximizes the irrigation water use efficiency for plants. Moreover, covering the surface of the sandy soil with a plastic

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sheet eliminates weeds that are harmful to the plant, consume a lot of irrigation water, and deprive the plant of benefiting from it, reducing the productivity of the onion crop. Also, applying the leaky pipe irrigation system in sandy soil reduces deep percolation losses of irrigation water and mineral fertilizers compared to the surface drip irrigation system. This ensures better utilization of resources within the effective roots zone, positively impacting onion crop productivity. Additionally, deficit irrigation techniques focus on maximizing onion yield while minimizing irrigation water usage. These findings are consistent with previous studies, (Doornebos and Kassam 1979; Kanani *et al.,* 2016; Memon *et al.,* 2017; Sadik and Ali 2018; Rasheed 2021; Lalisa *et al.,* 2022; Ali, 2023; Dache and Zewudie 2024).

3.3. Effect of CST and IR on seasonal ETa for onion crop under SDI and LPI irrigation systems

The data in Figures 1 and 2 indicate that the seasonal actual evapotranspiration (ETa) values for the winter onion crop decrease as irrigation levels (IR) decrease across all treatments. Additionally, the fully covered soil (FCS) technique demonstrated significant superiority over the uncovered (UCS) and half-covered soil (HCS) techniques in all treatments. Moreover, leaky pipe irrigation (LBI) had a more pronounced effect than surface drip irrigation (SDI). This trend was consistent across both the 2021/2022 and 2022/2023 seasons. The lowest seasonal ETa values were recorded under the FCS, IR = 40 %, and LBI treatment, with 114.56 mm and 110.67 mm for the respective seasons. In contrast, the highest ETa values were observed under the UCS, IR = 100 %, and SDI treatment, reaching 368.41 mm and 361.73 mm for both seasons, respectively. These findings may be attributed to the plastic sheet covering the sandy soil, which reduces surface evaporation. Moreover, the leaky pipe system is highly effective in light-textured soils, as it gradually controls deep percolation and operates with lower pressure than the surface drip irrigation system. This significantly reduces the evaporation of irrigation water from the soil surface. Additionally, adjusting the levels of irrigation water applied helps lower the evaporation rate from the sandy soil surface, thereby reducing actual irrigation water consumption; these results align with findings from previous studies, (Golabi and Akhoonali 2008; Terasaki *et al.,* 2009; Atta *et al.,* 2011; FAO, 2012; Kumar and Lal 2012; Yaghi *et al.,* 2013; Zhang *et al.,* 2014; (Enchalew *et al.,* 2016; Memon *et al.,* 2017; Sadik and Ali 2018; Ali 2023).

3.4. Effect of CST and IR on WUE and IWUE for onion crop under SDI and LPI irrigation systems

The data in Figures 1 and 2 indicate that the FCS, IR = 55%, and LBI treatment resulted in the highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for the winter onion crop, reaching 20.37 and 14.68 kg m^{-3} in the first season and 21.21 and 15.08 kg m^{-3} in the second season, respectively. In contrast, the UCS, IR = 100%, and SDI treatment recorded the lowest values, at 7.55 and 7.23 kg m^{-3} for the first season and 7.81 and 7.49 kg m^{-3} for the second season. Furthermore, the WUE and IWUE values under the FCS, IR = 55%, and LBI treatment showed a significant increase of approximately 170% and 103% in the first season and 172% and 101% in the second season, compared to the control treatment (UCS, IR = 100%, and SDI); these results can be attributed to the fact that completely covering the sandy soil with a plastic sheet ultimately reduces the loss of irrigation water through deep infiltration as well as evaporation from the soil surface, which increases the storage capacity of the sandy soil and thus provides large quantities of irrigation water and chemical fertilizers, as well as increasing the productivity of the onion crop. In addition, the leaky pipe irrigation system and deficit irrigation water help to increase the regularity of the distribution of added irrigation water along the planting line because there is no distance between the drippers. Onion is a dense crop. Allowed added irrigation water spreads slowly in the practical roots zone of the plant in a better way compared to the surface drip irrigation system, which reduces the loss of irrigation water through deep infiltration and evaporation from the soil surface, as well as increasing the productivity of the onion crop because it benefits from irrigation water and added fertilizers better, these findings are consistent with those reported by, Zotarelli *et al.,* (2009; Steduto *et al.,* (2012); Yaghi *et al.,* (2013); Kanani *et al.* (2016); Sadik and Ali (2018); Kunze *et al.,* (2021); Ali 2023; Tesfaye (2023)

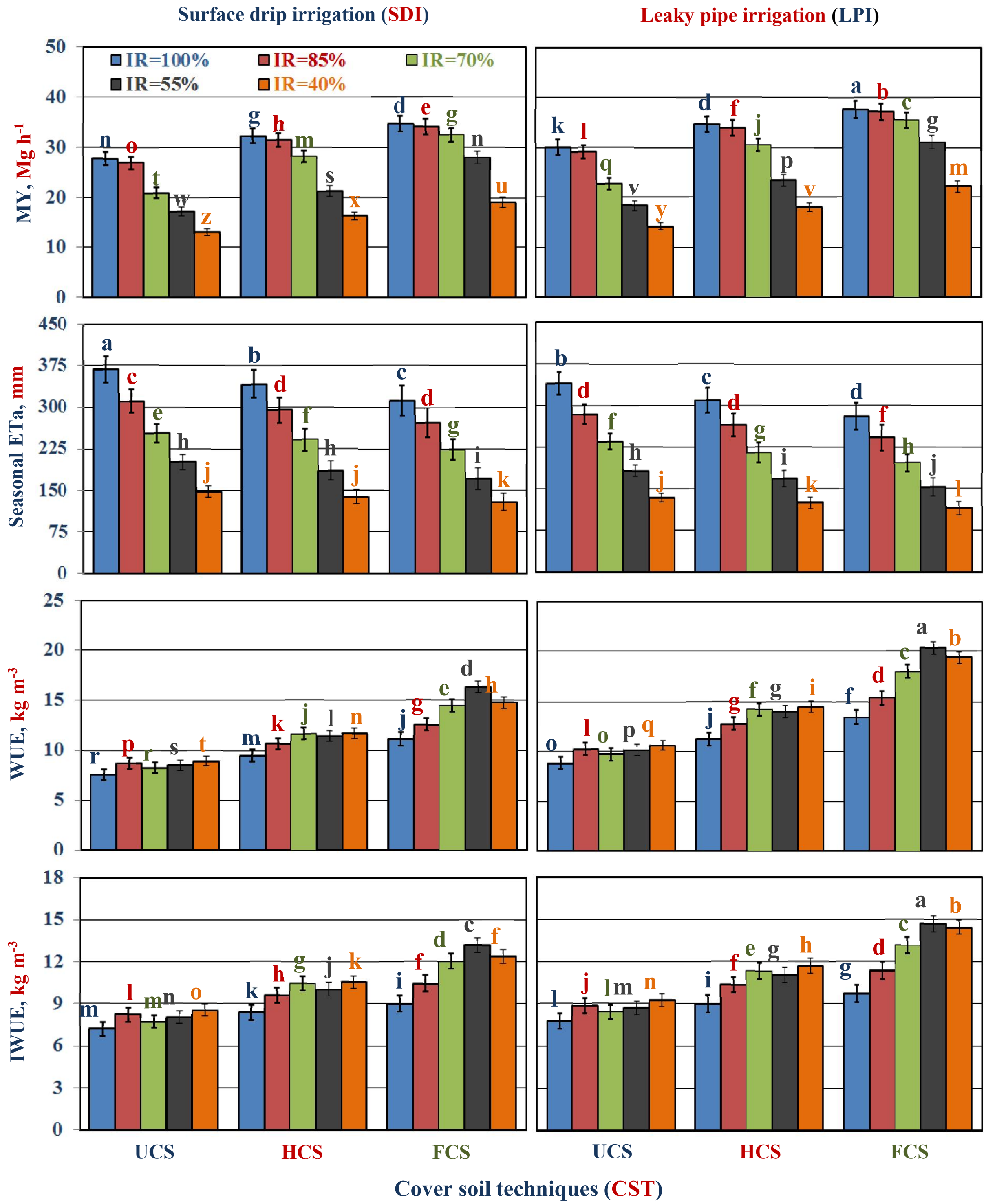

Fig. 1: Effect of cover soil techniques (CST) and added irrigation water levels (IR) on marketable yield (MY), seasonal actual evapotranspiration (ETa), water use efficiency (WUE) and irrigation water use efficiency (IWUE) of onion crop under SDI and LPI irrigation systems for season 2021/2022.

UCS: uncovered soil technique, **HCS:** half-covered soil technique, **FCS:** fully covered soil technique,

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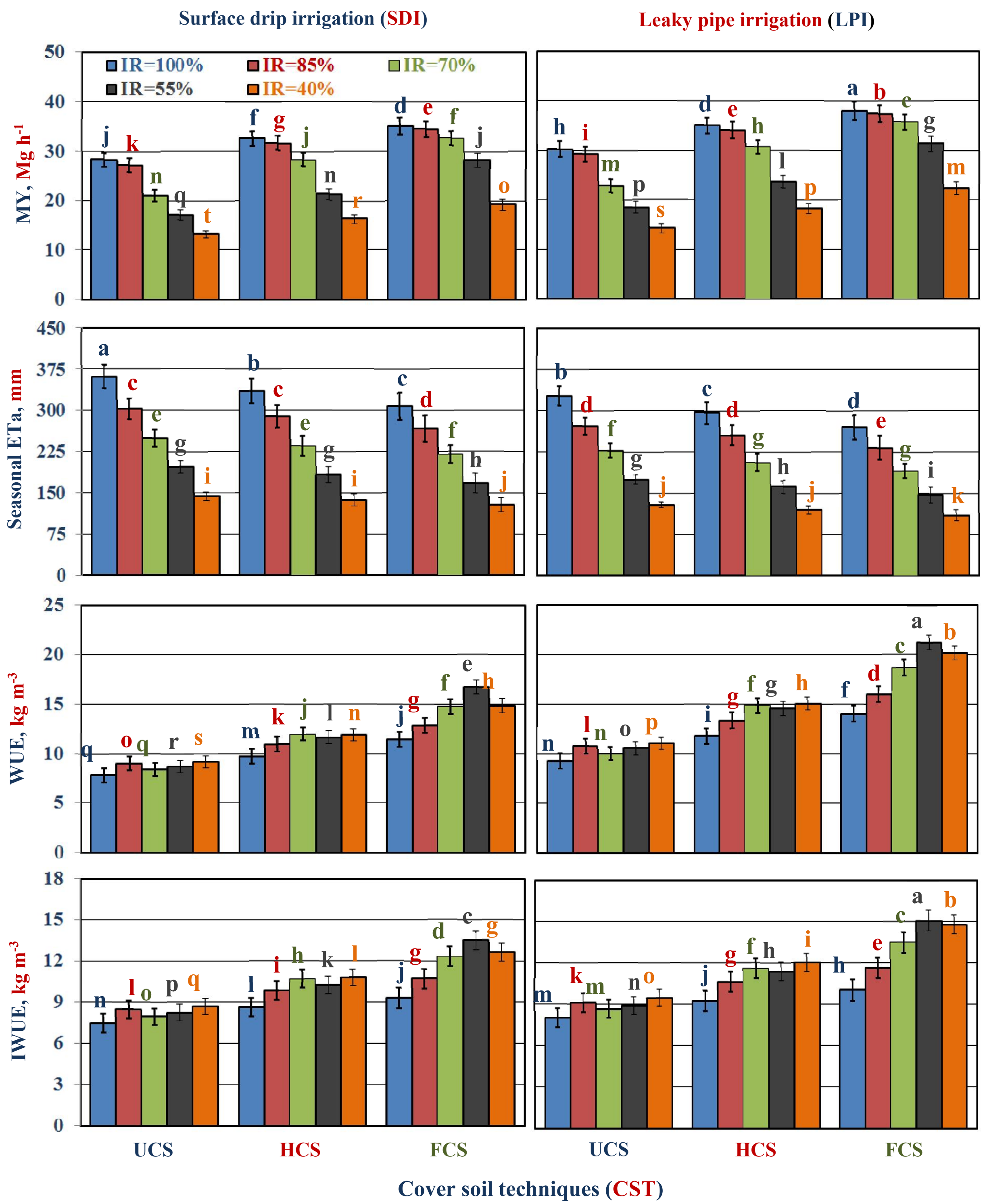

Fig. 2: Effect of cover soil techniques (CST) and added irrigation water levels (IR) on marketable yield (MY), seasonal actual evapotranspiration (ETa), water use efficiency (WUE) and irrigation water use efficiency (IWUE) of onion crop under SDI and LPI irrigation systems for season 2022/2023.

UCS: uncovered soil technique, **HCS:** half-covered soil technique, **FCS:** fully covered soil technique,

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3.5. Effect of CST and IR on Ky for onion crop under SDI and LPI irrigation systems

The data in Figure 3 indicate that the crop yield response factor (Ky) for winter onions demonstrates a linear relationship between the relative reduction in actual evapotranspiration, 1-(ETa/ETmax), and the relative reduction in yield, 1-(Ya/Ymax). These relationships for the 2021/2022 season showed a highly significant positive correlation, with Ky values of (r = 0.974**, 0.951**, and 0.887**) for UCS, HCS, and FCS, respectively, under the SDI treatment. Similarly, the Ky values were (r = 0.970**, 0.944**, and 0.875*) under the LPI treatment for UCS, HCS, and FCS, respectively. Furthermore, Figure 3 shows that the relationships between 1-(ETa/ETmax) and 1-(Ya/Ymax) in the 2022/2023 season followed the same trend across all soil coverage techniques under SDI and LPI treatments. Meanwhile, Figure 4 reveals that Ky values for winter onions decreased as irrigation levels (IR) increased across all soil coverage techniques under SDI and LPI treatments. The lowest Ky values were recorded under the FCS, IR = 85%, and LPI treatment, measuring 0.09 and 0.11 for the first and second seasons, respectively. In contrast, the highest Ky values were observed under the UCS, IR = 40%, and SDI treatment, reaching 0.88 and 0.89 for the first and second seasons, respectively; these results can be attributed to the fact that the yield response factor (Ky) indicates a crop's sensitivity to deficit irrigation. A yield response factor more significant than one suggests that the predicted yield reduction increases as deficit irrigation levels rise. Therefore, Ky is commonly used in irrigation management to optimize water use. These findings are consistent with those reported by Amer (2010); Steduto *et al.,* (2012); Enchalew *et al.,* (2016); Sadik and Ali (2018).

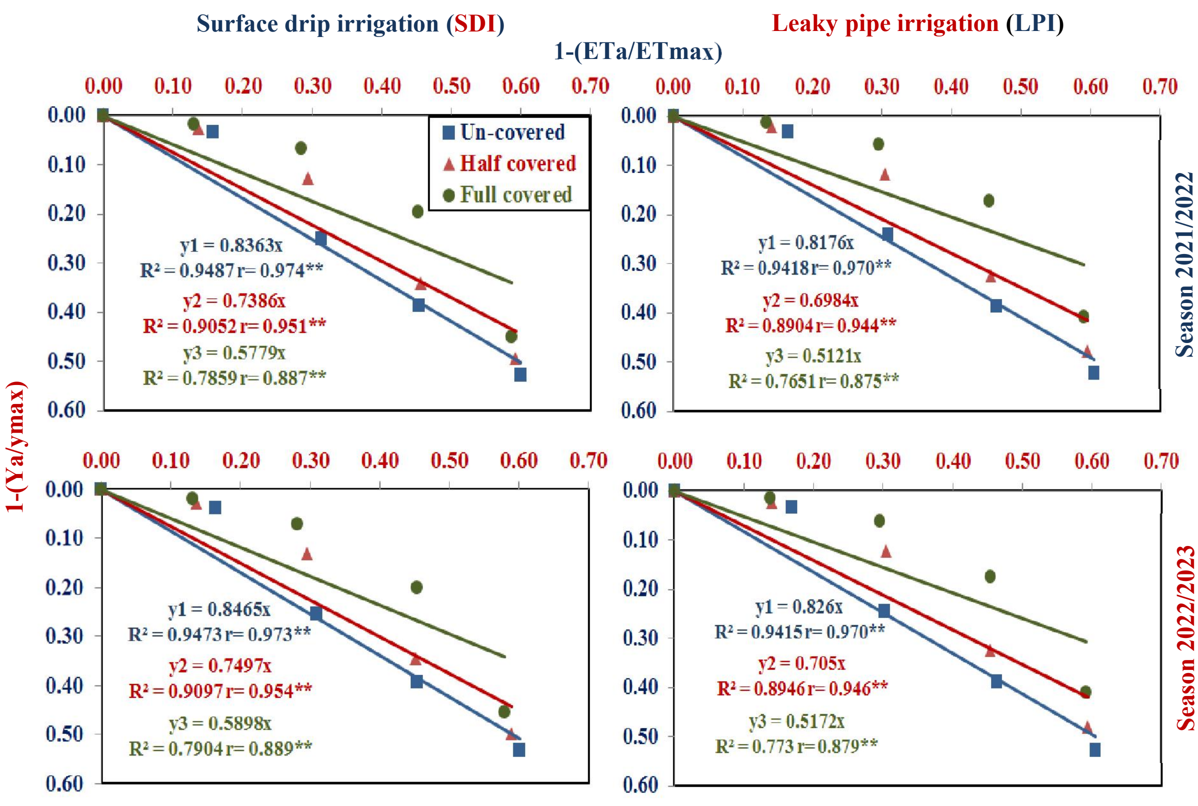

Fig. 3: Relationship between decrease in marketable yield (MY) and actual evapotranspiration stress (ETa), mm season^{-1} for onion crop under cover soil techniques (CST) and different irrigation systems (IS) for seasons 2021/2022-2022/2023.

***y1 at UN covered y2 at half covered y3 at full covered**

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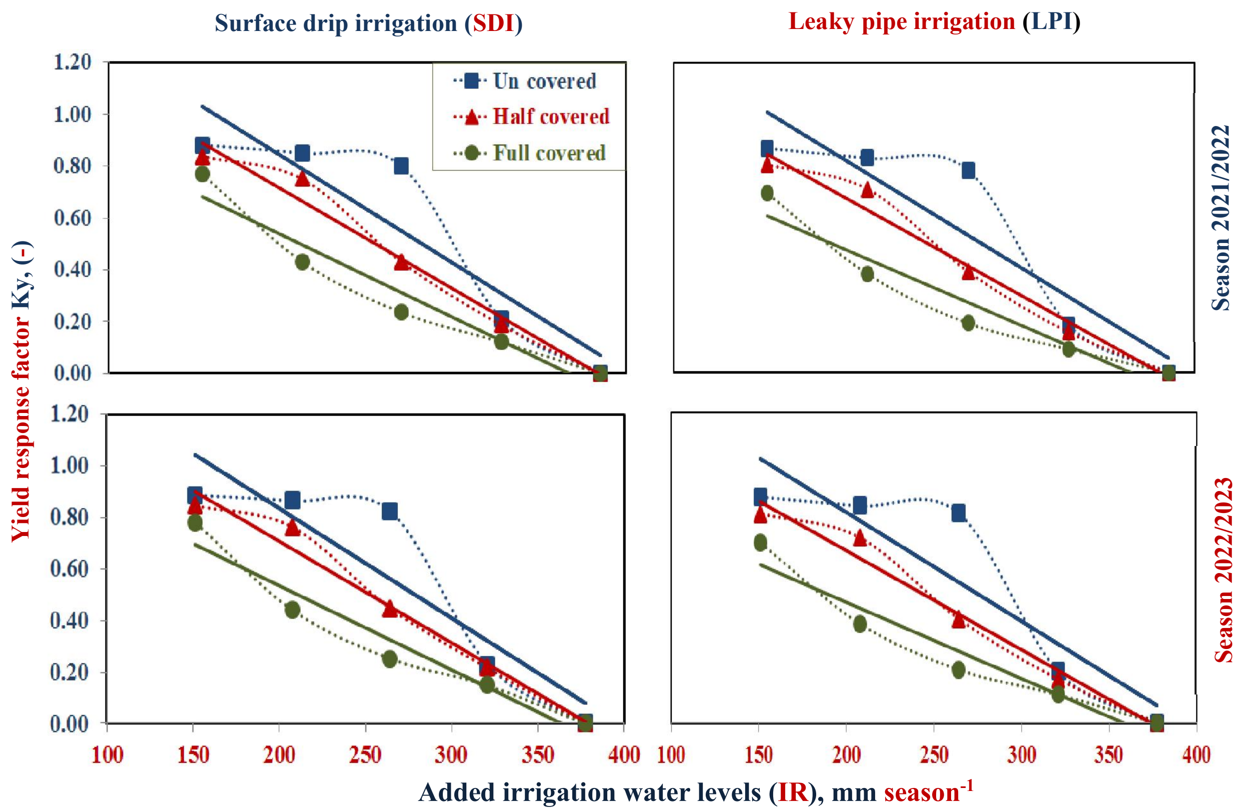

Fig. 4: Effect of added irrigation water levels (IR), mm season^{-1} on yield response factor (Ky) of onion crop under cover soil techniques (CST) and different irrigation systems (IS) for seasons 2021/2022-2022/2023.

3.6. Economic study for used full covered soil treatment

The FCS, IR = 55%, and LPI treatment proved highly economical due to the cost-effectiveness of implementing the technique. The process involved digging and covering canals with plastic sheets at a depth of 45 cm, requiring five hours of labor per feddan, costing 700 EGP per hour. Consequently, the total cost for digging and filling amounted to (5 hours × 700 EGP/hour = 3,500 EGP per feddan). Additionally, each feddan required approximately 250 kg of plastic sheets, costing 100 EGP per kg, resulting in a total plastic sheet expense of (250 kg × 100 EGP = 25,000 EGP per feddan). Thus, the overall cost of this treatment amounted to 28,500 EGP per feddan, with the plastic sheets having a lifespan of approximately five years. On the other hand, onions are cultivated once per year, and this treatment led to an increase in yield of about 3,250 kg per feddan compared to the control treatment (UCS, IR = 100%, and SDI). Assuming an onion price of 4 EGP per kg, the total revenue would be (3,250 kg × 4 EGP × 5 years = 65,000 EGP per feddan over five years). After deducting the initial implementation cost of 28,500 EGP, the net profit over five years amounts to 36,500 EGP per feddan. Moreover, this treatment conserves approximately 45% of the irrigation water, which could be redirected to reclaim additional desert land for cultivating the same crop. The added value of this reclaimed land further enhances the overall profitability of the technique.

4. Conclusions

This study assessed the effectiveness of soil cover techniques using plastic sheets along cultivation lines under different irrigation water stress levels, applied through surface and sub-surface drip irrigation, on winter onion yield and quality parameter, seasonal actual evapotranspiration (ETa), water use efficiency (WUE), irrigation water use efficiency (IWUE), and crop yield response factor (Ky) in the sandy soil of Matrouh. The results indicate that the highest values for quality parameters and marketable yield of the winter onion crop were achieved under the FCS, IR = 100%, and LPI treatment. Meanwhile, the lowest seasonal ETa values were recorded under the FCS, IR = 40%, and LBI treatment. Additionally, the minimum Ky values for the winter onion crop were 0.09 and 0.11 in the first and second seasons, respectively, under the FCS, IR = 85%, and LBI treatment. Furthermore, the WUE and IWUE values increased significantly under the FCS, IR = 85%, and LBI treatment, by approximately 170% and 103% in the first season and 172% and 101% in the second season, respectively, compared to the control treatment (UCS, IR = 100%, and SDI). Therefore, it is recommended to implement the FCS, IR = 55%, and LPI treatment for winter onion cultivation under Matrouh conditions. This treatment can save approximately 45% of applied irrigation water while increasing the marketable yield of winter onions by an average of 12% across both seasons compared to the control treatment (UCS, IR = 100%, and SDI).

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